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IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

APPLICATION FOR UNITED STATES LETTERS PATENT

Title:

INTEGRATED LITHIUM NIOBATE BASED OPTICAL TRANSMITTER

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INTEGRATED LITHIUM NIOBATE BASED OPTICAL TRANSMITTER

TECHNICAL FIELD

An improved optical transmitter is disclosed. More specifically, an optical transmitter is disclosed with an integrated design whereby a lithium niobate chip is provided with a plurality of interferometers disposed therein that are in alignment with an output of a stacked laser array. The lithium niobate chip also includes a coupler or multiplexer for combining the plurality of output signals from the laser array into a single combined output signal.

BACKGROUND OF THE RELATED ART

Fiber optic transmission uses the same basic elements as copper-based transmission systems. Specifically, both systems utilize transmitters and receivers and a medium by which a signal is passed from the transmitter to the receiver. Instead of a copper wire, optic transmission systems use an optical fiber.

Typically, a fiber optic transmitter uses a laser diode or other light emitting device (LED) to optically encode information and generate an optical output at various light wavelengths, *e.g.*, 850 nm, 1310 nm, 1550 nm etc. The optical fiber connects the transmitter to a receiver which then converts the optical signal to an electrical signal. The optical fiber may be either single-mode or multi-mode. Typical receivers incorporate optoelectronic transducers such as photodiodes to convert the optical signal to an electrical signal. A data recovery circuit then converts the data back into its original electrical form.

In order to increase transmission rates, wavelength division multiplexing (WDM) was developed for sending several different signals through a single fiber at different wavelengths. WDM components allow these separate signals to be joined into a composite output signal for transmission and then separated back into their original signals at the receiver end. Coarse wavelength division multiplexing (CWDM) is typically used up to 16 channels and dense wavelength division multiplexing (DWDM) allow up to several hundreds of signals to be combined into a single fiber. DWDM allow a multiple wavelength transmission in the C-Band (1550 nm) and more recently in the S-Band and L-Band as well. CWDM schemes have been used in many wavelength bands including near 850 nm, 1300 nm and all bands at 1500 nm.

However, despite the ability to transmit multiple signals over a single optical fiber, the transmitters of each signal continue to be single wavelength devices. Specifically, a typical transmitter includes a laser diode or other light emitting device coupled to a modulator which then outputs the modulated signal either directly or indirectly to the optical fiber. Typically, an isolator and various lens arrangements are disposed between the laser diode and the modulator. Also, a tap photodiode may also be included to measure the outputted signal.

The use of separate transmitters for each signal increases the size and complexity of the wavelength division multiplexing apparatus. Not only does the use of separate components for each signal add to the manufacturing time and cost, the incorporation of additional components into any optical transmission system further increases the possibility of defective products because of the precise alignment that is required between each component. Thus, reducing the number of components not only reduces the size and cost of each assembly, reducing the number of components also increases manufacturing efficiency.

As a result, there is a need for improved optical transmitter designs which are capable of transmitting multiple signals at multiple wavelengths and which reduce the total number of components needed to perform such a wavelength division multiplexing transmission.

BRIEF DESCRIPTION OF THE DRAWINGS

The disclosed apparatuses and methods will be described more or less diagrammatically in the accompanying drawing, wherein:

Fig. 1 is a schematic illustration of a four wavelength integrated transmitter made in accordance with this disclosure; and

Fig. 2 is a schematic illustration of one of the Mach-Zehnder interferometers of the transmitter shown in Fig. 1.

DETAILED DESCRIPTION OF THE PRESENTLY PREFERRED EMBODIMENTS

A schematic illustration of an integrated four wavelength transmitter 10 made in accordance with this disclosure is provided in Fig. 1. It will be noted that while the transmitter 10 illustrated in Fig. 1 includes four separate light sources and four separate modulators, the apparatus illustrated in Fig. 10 could be expanded to

more or less than four wavelengths. This disclosure is clearly not limited to a four wavelength device.

As shown in Fig. 1, an array 11 of lasers 12 is provided. The lasers 12 may be distributed feedback (DFB) lasers with each having a fixed wavelength, or the lasers 12 may be tunable lasers such as multisection distributed brag reflector (DBR) lasers. Preferably, each laser 12 generates light of a different international telecom union (ITU) wavelength. Again, more or less than four lasers 12 may be provided.

The laser array 11 is coupled to a lenslet array 13 which, in the embodiment shown in Fig. 1, includes four lenses 14, that are aligned with the four lasers 12. In other words, the lenslet array 13 provides a single lens 14 for each laser 12, and the number of lenses 14 preferably corresponds to the number of lasers 12. Thus, in the example shown in Fig. 1, a 4 x 1 lenslet array 13 is preferred.

The lenslet array 13 is disposed between the laser array 11 and an optical isolator 15. The isolator 15 acts to block out unwanted back reflection of light into the laser diodes. Typically, the isolator 15 will include a crystal Faraday rotator disposed within a permanent magnet and that is sandwiched between a polarizer and an analyzer (not shown) as is known to those skilled in the art.

The output signals from the lasers 12 then exit the isolator 15 and pass through a second lenslet array 16 which, again, includes a plurality of lenses 17, each lens 17 corresponding to an output signal from one of the lasers 12. The lenslet array 16 is disposed between the isolator 15 and a lithium niobate ($LiNbO_3$) based chip 18.

The chip 18 includes a plurality of modulators 19 in a stacked configuration so that each modulator 19 is in alignment with the output from one of the lasers 12, after the output is passed through the arrays 13, 16 and isolator 15. In an embodiment, the modulators 19 are interferometers. Preferably, the modulators 19 are Mach-Zehnder interferometers (MZIs) as shown below in Fig. 2. The modulators apply modulation to each output signal for purposes of turning on and off the data stream or applying other forms of modulation to the carrier wavelength such as phase modulation. The MZIs 19 typically perform this function at a speed of about 10 Gb/s.

The output from each modulator 19 is then inputted to a coupler or multiplexer 21. The coupler or multiplexer 21 functions to combine the separate output signals into a single combined output signal shown at 22. The coupler 21 may also be a cascade of splitters or couplers or a multi-mode interference coupler (MMI) as shown in Fig. 1. The coupler 21 is also incorporated into the lithium niobate chip

18. A tap photodiode 23 may also be incorporated into the lithium niobate chip 18 for purposes of monitoring the combined output signal 22. The combined output signal 22 may then be directed at a optical fiber 24 which, then, may be coupled to a receiver (not shown).

A Mach-Zehnder interferometer 19 is illustrated in greater detail in Fig. 2. Within the lithium niobate chip 18, a waveguide 30 is formed having two divergent paths 30a, 30b as shown. Modulating voltage is applied to the waveguide 30 by way of the electrodes 31, 32. The modulating voltage causes a variation of the relative phase differences between the two paths 30a, 30b. At the output waveguide 30c, the two waves recombine as the sum of the two modes--the fundamental mode which is guided and a higher-order mode which is unguided and radiated away. As the path 30, 30b difference varies, the proportion of power in each mode changes and the guided output power is modulated.

By providing an array of modulators within a single lithium niobate chip 18, in combination with an array 11 of lasers, in combination with the lenslet arrays 13, 16 and isolator 15, the number of components has been reduced significantly. Specifically, for the four wavelength embodiment illustrated in Fig. 1, previously, four different transmitters would have been required. However, the design as disclosed herein enables an array of wavelengths to be handled by a signal transmitter. Again, the number of wavelengths in the array may be more or less than four.

Although lithium niobate ($LiNbO_3$) is the preferred material of construction for the chip 18, other suitable materials include, but are not limited to, InP, GaAs and various polymers that will be apparent to those skilled in the art.

Although a certain apparatus constructed in accordance with the teachings of this disclosure has been described herein, the scope of coverage of this patent is not limited thereto. In the contrary, this patent covers all embodiments of the teachings of this disclosure fairly falling within the scope of the appended claims, either literally or under the doctrine of equivalents.